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Literature Survey for Collaborative Displays

Final Report

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Contract Report

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Abstract

A literature review project has been completed to investigate the literature on collaborative displays as they relate to command and control in general and naval command and control specifically. Using a defined set of keywords and literature sources the project team identified a total of 461 papers, of which 392 of the most relevant papers have been rated using a literature relevance matrix. Of the literature identified in the search, 21 papers were reviewed in detail in Phase II. The literature review identified a series of weaknesses in the collaborative display literature related to practical evaluations of the technology, lack of human performance testing, lack of context in the research, and an absence of research to investigate the scaling of technology from single person to collaborative displays. To address weaknesses in the literature, and to develop guidance for future acquisition projects and operational teams, a three pronged R&D program is recommended to (i) extend the literature review and theoretical development of the domain, (ii) experiment with naval collaborative displays, and (iii) coordinate and integrate collaborative display research throughout DRDC/DND.

Résumé

Nous avons réalisé un projet de recension des écrits sur les affichages partagés pour évaluer leur utilité pour le commandement et le contrôle en général, et pour le commandement et le contrôle navals en particulier. À partir d'un ensemble défini de mots-clés, l'équipe de projet a recensé 461 articles dans un ensemble de banques documentaires. Elle a ensuite classé les 392 articles les plus appropriés (pertinents) avec un tableau de pertinence. Au cours de la phase II, elle fait l'étude détaillée de 21 de ces articles. Notre examen des écrits nous a permis de dégager certaines faiblesses des articles, notamment : l'évaluation pratique de cette technologie, le manque d'essais sur la performance humaine, le manque de contexte pour la recherche et l'absence de recherche sur comment modifier la technologie pour passer des affichages individuels aux affichages partagés. Pour éliminer ces faiblesses dans les écrits et élaborer les consignes à suivre à l'avenir lors de projets d'achat et par les équipes, on recommande de mettre en œuvre un programme de R. et D. comportant trois volets, soit (i) élargir l'étude de recension des écrits et le développement théorique du domaine, (ii) procéder à des essais avec les affichages partagés et (iii) coordonner et intégrer les recherches menées sur les affichages partagés au sein de RDDC/MDN.

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Executive summary

This document is the final report of a project to review the literature on collaborative displays as they relate to command and control in general and naval command and control specifically. The report has been prepared by Options Incorporated for the Defence and Civil Institute of Environmental Medicine under contract No. W7711-997593/001.

The project was requested to be completed in two phases, such that Phase I provided an assessment of the scope (breadth and depth) of the immediately available literature, and Phase II then progressed to review a subset of the literature to provide an assessment of the relevance of the literature to command and control, including the quality of the studies.

Using a defined set of keywords and literature sources the project team identified a total of 461 papers, of which 392 of the most relevant papers have been rated using a literature relevance matrix. Of the literature identified in the search, 21 papers were reviewed in detail in Phase II.

The literature identified had a number of weaknesses, in terms of the ability to derive requirements for the acquisition or development of collaborative displays. These weaknesses included:

- There is very little literature on the testing of display concepts in the field and relatively low levels of literature on laboratory tests.
- The literature on supporting technologies is often lacking in human performance testing. There is a gap in the understanding of how these technologies influence human performance.
- The literature on team performance is often lacking in testing the influences of technology on performance. The reverse of the previous point, the researchers on team performance have often neglected to study the impact of technology on team performance.
- It is unclear how applicable Business application research will be to the Naval command and control environment without examining the papers in further detail.
- There are no papers that examine the scaling of technology from single person displays to collaborative displays, or from collaborative displays to uses in reduced team situations.

To address weaknesses in the literature, and to develop guidance for future acquisition projects and operational teams, a three pronged R&D program is recommended:

1. Extension of Literature Review and Theoretical Development. The literature review should be extended to further define the collaborative aspects of naval command and control (which may also require task analysis), to propose measures of team performance and shared cognition in the naval environment, to further investigate the theoretical differences between individual and

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collaborative decision making, and to further identify any known impacts of collaborative technology on team performance.

2. Experimentation with Naval Collaborative Displays. An experimental environment must be created for naval command and control, perhaps making use of existing simulations in this area. Once this experimental platform is established, then the recommended future R&D in the areas of (i) extending individual interface design to collaborative displays, (ii) comparing individual and collaborative decision making, and (iii) developing a deeper understanding of distributed cognition or shared situation can be investigated.

3. Coordination of Collaborative Display Research. A program of research in the human factors aspects of collaborative displays, with a goal of generating requirements and design guidance for future military acquisitions, requires a coordination function. Not only is there the opportunity to centrally compile and distribute the results of research in the areas described above, but also to coordinate the application of collaborative measures applied on other experimental programs in DRDC/DND.

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Sommaire

Nous présentons le rapport final d'un projet de recension des écrits scientifiques sur les affichages partagés, visant à évaluer leur utilité pour le commandement et le contrôle, en général, et pour le commandement et le contrôle navals en particulier. La *Options Incorporated* a rédigé ce rapport à l'intention de l'Institut de médecine environnementale pour la défense, dans le cadre du contrat W7711-997593/001.

Le projet comportait deux phases. Au cours de la phase I, nous avons évalué l'ampleur du corpus publié dans le domaine (tant en étendue qu'en profondeur), tandis qu'au cours de la phase II, nous avons étudié un sous-ensemble de ce corpus pour en évaluer la pertinence pour le commandement et le contrôle, notamment la qualité des articles.

À partir d'un ensemble défini de mots-clés et de sources, l'équipe de projet a recensé 461 articles, dont 392 des plus pertinents ont été évalués à l'aide d'un tableau de pertinence. Au cours de la phase II, elle a fait l'étude détaillée de 21 de ces articles.

Dans ces écrits, nous avons dégagé un certain nombre de faiblesses relativement à la capacité de définir des exigences en vue de l'achat ou de la mise au point d'affichages partagés, notamment :

- Il existe peu d'écrits sur les essais de concepts d'affichage en situation réelle et à peine plus sur les essais en laboratoire.
- Lors des essais sur les performances humaines, on discute peu de technologies de soutien. On comprend mal comment ces technologies influencent la performance humaine.
- Souvent dans les articles sur la performance des équipes, on ne discute pas des tests sur l'influence de la technologie sur la performance. À l'inverse du point précédent, les chercheurs ont souvent négligé de considérer l'impact de la technologie sur la performance des équipes.
- Sans une étude détaillée des articles, on ne peut savoir comment la recherche sur les applications de bureau sera transposable au commandement et au contrôle navals.
- On n'a pas publié d'article présentant une étude sur le passage des affichages individuels aux affichages partagés, ou des affichages partagés aux utilisations par des équipes réduites.

Pour éliminer ces faiblesses dans les écrits et élaborer les consignes à suivre à l'avenir lors de projets d'achat et par les équipes, on recommande de mettre en œuvre un programme de R. et D. comportant trois volets :

1. Élargissement de l'étude de recension des écrits et du développement théorique. Il y aurait lieu d'élargir l'étude de recension des écrits afin de mieux définir les aspects partagés du commandement naval et du contrôle naval (ce qui peut également exiger l'analyse des tâches), de proposer des mesures de la performance des équipes et de la cognition partagée dans le milieu de la marine militaire, d'examiner plus à fond les différences théoriques entre les processus décisionnels individuel et partagé, et de

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déterminer plus précisément tout impact connu de la technologie de collaboration sur la performance des équipes.

2. Essais avec les affichages partagés. Il faut créer un environnement expérimental pour le commandement naval et le contrôle naval, peut-être en exploitant les simulations qui existent déjà dans ce domaine. Lorsque cette plate-forme expérimentale aura été établie, on pourra alors étudier les futurs travaux de R. et D. dont on recommande l'exécution dans les domaines suivants : (i) application de la conception des intervalles individuels aux affichages partagés; (ii) comparaison des processus décisionnels individuel et partagé et (iii) amélioration des connaissances sur la cognition distribuée ou sur les situations partagées.

Coordination des recherches sur les affichages partagés. Tout programme de recherche portant sur les aspects relatifs aux facteurs humains des affichages partagés, qui est mis en œuvre en vue d'établir des exigences et d'élaborer des consignes en matière de conception en prévision des futurs achats de nature militaire, doit comporter une fonction de coordination. Outre l'occasion qu'elle offre de centraliser puis de distribuer les résultats des recherches réalisées dans les domaines décrits ci-dessus, une telle fonction permet également de coordonner la mise en oeuvre de mesures de collaboration appliquées à d'autres programmes expérimentaux à RDDC/MDN.

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1. Introduction

This document is the final report of a project to review the literature on collaborative displays as they relate to command and control in general and naval command and control specifically. The report has been prepared by Options Incorporated for the Defence and Civil Institute of Environmental Medicine under contract No. W7711-997593/001.

1.1 Background

The Canadian Navy has identified decision support as a focus of attention in the upgrade to the Canadian Patrol Frigate (CPF), anticipated for the 2005-2010 period. One area that the Navy feels warrants further investigation is the utility of collaborative or "shared" displays for some or all members of the operations room team.

In order to determine the utility of collaborative displays, and the requirements for these displays if they are known, the Defence and Civil Institute of Environmental Medicine (DCIEM) has requested that a literature survey be conducted on the human factors issues for collaborative displays.

1.2 Objective

The overall intentions of the literature survey project were to:

1. review the basic and applied research literature concerning the use of various types of collaborative displays,
2. assess the relevance of the findings to the Command and Control community, and make recommendations for future research in this area.

1.3 Scope

The scope of this project was established through the Statement of Work developed by the Scientific Authority, combined with limits placed on the number of papers that could be reviewed within the project budget.

The project was requested to be completed in two phases, such that Phase I provided an assessment of the scope (breadth and depth) of the immediately available literature, and Phase II then progressed to review a subset of the literature to provide an assessment of the relevance of the literature to command and control, including the quality of the studies.

In order to remain within the project budget it was determined that up to 350 papers would be entered into the project database in Phase I while approximately 15 papers would be reviewed in detail in Phase II.

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1.4 Deliverables

The deliverables required from this literature survey project included:

- A Phase I Report summarizing the breadth and depth of the literature.
- A Phase II Report (final report), expanding on the Phase I report to further assess the relevance of the literature and to determine the future Research and Development (R&D) activities that may be required.
- An annotated bibliography which summarizes the literature, submitted in Endnote™ database format.

2. Method

The collaborative display literature survey was conducted through the method outlined in the following subsections.

2.1 Phase 1: Literature Survey and Preliminary Review

The project Statement of Work called for a Phase I survey to assess the scope (breadth and depth) of the immediately available literature related to collaborative displays. This was to be followed in Phase II with an assessment of the relevance of the papers to command and control, including the quality of the study, to provide some weight to the guidance offered from any one paper.

The method applied by the Options Inc. team resulted in some of the classification intended for Phase II to be completed in Phase I, to minimize the number of times the literature had to be processed within the project scope. As a result, Phase I activities included literature search and preliminary review in order to classify the type of paper and the level of research (or methodological quality).

2.1.1 Literature Survey Strategy

The project began with the entire team meeting to develop the literature search strategy. This planning was guided by the team defining collaborative displays for the purpose of the project, defining command and control impacts of collaborative displays, identifying the key search terms required, and identifying the sources of papers that should be searched.

It was determined that an iterative search strategy would be utilized, such that the literature sources would be searched in multiple passes. It was felt that this method would allow the team to identify the most relevant papers on the first pass, and then return to obtain another level of papers. These iterations allowed the incremental identification of literature, prioritized by project goals while at the same time allowing the team to remain within the project scope.

2.1.2 Keywords

As a result of the project planning activities, a matrix of keywords were used in the literature search. These keywords are listed in Table 1 below. Within Table 1 the first column represents the "1st keyword" while the "AND #" columns represents the keywords used individually in conjunction with the initial key word (e.g. cooperative AND display, cooperative AND decision making, cooperative AND situation awareness, etc.).

These keywords were arranged into three groups:

1. Collaborative Display. These keywords focused on the concept of collaborative displays and some of the key human behaviour that would

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underlie performance impacts of collaborative display use (such as situational awareness or decision making performance).

2. Basic Research Issues. These keywords were based in basic research issues that likely relate to collaborative display requirements, with some modifiers to the search string to focus more on collaborative issues.

3. Technology Area. Preliminary literature reviews, previous team member experiences, and the project definition of collaborative displays were all used to generate a list of likely technology areas that would be relevant to collaborative display projects.

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Table 1: Literature Search Keywords

1st keyword	AND 1	AND 2	AND 3	AND 4	AND 5	AND 6
Collaborative Display and Underlying Human Behaviour						
cooperative	display	decision making	situation awareness	planning	command and control	communication
collaborative	display	decision making	situation awareness	planning	command and control	communication
team	display	decision making	situation awareness	planning	command and control	communication
shared	display	decision making	situation awareness	planning	command and control	communication
group	display	decision making	situation awareness	planning	command and control	communication
distributed	display	decision making	situation awareness	planning	command and control	communication
computer supported cooperative work	problem solving	decision making	military	collaborative	display	requirements
teamwork	display					
common operating picture						
Basic Research Issues						
cognition	shared	group	team			
awareness	shared	group	team			
reasoning	shared	group	team			
visual Search	display	shared display	collaborative display	large display		
interaction	gesturing	direct voice input	input devices	large display		
Technology Area						
PDA	team	group	collaborative	cooperative		
groupware	team	group	collaborative	cooperative	study	evaluation
group view	team	group	collaborative	cooperative	study	evaluation
large screen	team	group	collaborative	cooperative	study	evaluation
symbol or symbology	display	large display				
3d display	team	group	collaborative	cooperative	study	evaluation
electronic sandbox	team	group	collaborative	cooperative	study	evaluation
electronic whiteboard	team	group	collaborative	cooperative	study	evaluation
video conferencing	command and control	military				

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Keywords and topic areas deemed out of scope (due to large number of papers that were likely to result, many of which would not be directly relevant to the collaborative nature of displays) , and were therefore not used in this review included:

- Knowledge management
- Artificial Intelligence (AI)
- Virtual Agents
- Natural language
- Speech Synthesis

2.1.3 Target Literature Databases

The literature search was conducted using five primary sources of material:

- Scientific Literature Databases. The majority of the literature was obtained by searching scientific literature databases accessed through the University of Waterloo.
- Department of National Defence Databases. A search request was made through the DRDC Directorate of R&D Communications and Information Management to search for military specific papers, both within Canada and from other nations.
- Limited General Internet searching. A limited amount of Internet search was conducted using a subset of the keywords, primarily to identify military projects that had used collaborative displays and to identify key technology areas.
- Military Labs, Military Organizations. A limited amount of Internet searching was conducted for military papers. This included extensive searching using the Defence Research and Development Canada (DRDC) search tools (CANDID on the Internet) as well as some searching of related labs such as those at DERA, US ARL, and TNO.
- Options Team literature sources. Members of the project team had been involved in a range of information system projects involving collaborative displays, command and control, and naval command and control. Team members provided relevant papers to the literature pool for the project.

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Within the Scientific Literature a number of databases were searched, including:

- CISTI
- Psych Info
- COMPENDEX
- Ergo Abstracts
- NASA
- Computer Supported Cooperative Work (CSCW)
- Computer Human Interaction 1995 to 1998

To ensure that these larger compendiums of literature were not missing anything relevant some specific society databases were searched using the keyword matrix, including:

- Human Factors and Ergonomics Society 1999 and 2000.
- Association of Canadian Ergonomists
- Interservice Industry Training Simulation and Education Conference (IITSEC)
- Electrical Power Research Institute (EPRI), IEEE
- Computer Human Interface (CHI), Association for Computing Machinery (ACM), Computer Supported Cooperative Work (CSCW)
- Telecom

2.2 Literature Rating System

Once relevant titles were obtained they were further reviewed and categorized using a matrix of terms. This matrix was created to meet one of the project goals which was to provide an indication of (1) the relevance to command and control and (2) the quality of the study, including an index of the methodological quality.

The matrix used had two axes:

1. Level of Experimentation. This included four levels of classification, prioritized in terms of the quality of the results or research. From lowest quality to highest quality these categories included:
   - Vision or Concept Paper.
   - Laboratory Experiment.
   - Field Evaluation or Operational Experience.
   - A Review Paper (a review of several experiments or studies).

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2. Domain Relevance. This axis included five levels of relevance. Relevance was evaluated in terms of the ability of the results to immediately useful guidance to the development of requirements for naval command and control systems. The five levels of relevance, from lowest to highest, included:

   - Basic Research
   - Business Applications (eg: Management)
   - Industrial Applications (eg: Process Control)
   - Military Command and Control
   - Naval Command and Control

Figure 1 illustrates the resulting matrix. The numbers in each cell were used to code or categorize the papers entered into the project Endnote™ database. These categorizations were reviewed by three team members to develop consensus and to ensure accuracy.

LEVEL OF EXPERIMENTATION						
	Review Paper	*Cell 4*	*Cell 8*	*Cell 12*	*Cell 16*	*Cell 20*
	Field Eval/Ops	*Cell 3*	*Cell 7*	*Cell 11*	*Cell 15*	*Cell 19*
	Laboratory	*Cell 2*	*Cell 6*	*Cell 10*	*Cell 14*	*Cell 18*
	Vision/Concept Non-Tested Prototype	*Cell 1*	*Cell 5*	*Cell 9*	*Cell 13*	*Cell 17*
		Basic Research	Business	Industrial	Mil C2; Space & other C2	Navy C2
		DOMAIN RELEVANCE				

Figure 1: Literature Rating Matrix

2.3 Phase II: Detailed Literature Review

In Phase II of the project, 21 of the papers were selected for detailed review. This selection was based on a review of the abstracts of the literature listed in Annex A, in consultation with the scientific authority and other researchers at DCIEM

Once the detailed literature was completed, an assessment of the breadth, depth, and quality of the literature was developed, along with recommendations for areas of

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further research in the future. These final assessments were integrated into this report.

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3. Results

3.1 Collaborative Displays Defined

For the purposes of this project, Collaborative Displays have been defined as:

> *"individual and/or group format displays that provide information to a collocated and/or distributed user population to support simultaneous (real time) command and control activities."*

Key distinctions in this definition include:

1. Individual and/or Group Format. This means that a collaborative display may result from a group of users each with their own display working in a collaborative fashion from their workstation. Alternatively, a collaborative display may also result from a large overview, or group view, display shared by a number of personnel.
2. Collocated and/or Distributed. This means that the personnel using the collaborative display may be collocated in the same room, or they may be distributed across different rooms or operating platforms. The distributed display category introduces human computer interface issues associated with mobile technology such as Personal Digital Assistants (PDAs), or palm based computers, which appear likely to be introduced to command environments resulting in command team members participating in tactical and communication activities from any location within the nearby operating environment (in a naval context, anywhere on the ship, or in shore when in port).
3. Simultaneous (Real Time). This distinction means that collaborative displays are bound by real time interaction and participation of the team. This distinction is made to differentiate between collaborative displays and distributed planning or distributed design tools that allow multiple users to contribute but not at the same time. Collaborative displays focus on simultaneous interaction of the team.

3.2 Collaborative Displays in Naval Command and Control

For the purposes of this project, Collaborative Displays have been defined as:

Throughout the course of the project it became clear that regardless of the relative benefits for collaborative displays indicated in the literature, that this technology will be further developed and likely deployed in the naval environment. This conclusion was based on the following observations:

1. In the United States, their future ship projects such as DD21, and related R&D activities such as the Integrated Command Environment (ICE) rely heavily on collaborative displays concepts in future operating room environments.
2. A DRDC team has recently completed a review of technologies applicable to the reduction of crew size and workload on Canadian Naval vessels (Beevis,

Vallerand, and Greenley 2001). During the course of this work a number of sources indicated various roles for collaborative displays:

a. Focus groups with ship personnel (Greenley 2001) indicated that, in their opinion, one of the key technologies to reduce crew demands in the operations room was the installation of group view displays.

b. The use of Tele-presence was a prevalent technology proposed for future ships, for command and control, medicine, and maintenance.

c. Wireless technology on board ship is expected to allow personnel to continue to interact with various ship teams while at another location onboard, using Personal Digital Assistants or some future form of wearable computer.

3. Current naval projects, such as the upgrade to the CANTASS system, or future systems such as that reflected in TIAPS, continually point to future integration of ship information and the sharing of information between sensor operator stations and between ships. This continual fusion of command and control related information forms the core information repository to support collaborative work and linked or shared displays.

3.3 Phase I: Literature Search

Using the keywords and literature sources outlined in Section 2.0 the project team identified a total of 461 papers, of which 392 of the most relevant papers have been rated using the project matrix (slightly beyond the intended maximum scope of 350 papers). This literature was categorized using the project rating matrix, to produce the literature distribution illustrated in Figure 2.

LEVEL OF EXPERIMENTATION						
	Review Paper	12	24	14	15	5
	Field Eval/Ops	0	1	0	2	2
	Laboratory	21	22	19	54	9
	Vision/Concept Non-Tested Prototype	3	74	20	74	21
		Basic Research	Business	Industrial	Mil C2; Space & other C2	Navy C2
		DOMAIN RELEVANCE				

Figure 2. Literature Search and Categorization Results.
(the numbers in each cell indicates the number of papers in the project bibliography assigned to that cell)

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3.4 Phase I: Review of Literature Search Results

The literature identified were categorized in terms of breadth in Figure 3.

The types of papers identified indicated that there were many relevant papers in the Naval and Military categories. Not surprisingly, the number of Military papers (37%) outnumbered the papers related directly to Naval work (9%).

The number of papers identified in the Basic Research category (9%) does not reflect the complete literature base in this area, but rather a sampling of the papers that appeared to be most relevant to naval collaborative displays.

There is a substantial base of literature from Business applications (31%), most of which is directed at collaborative work, team management or conferencing. There was noticeably less literature from more complex Industrial domains (14%) such as process control.

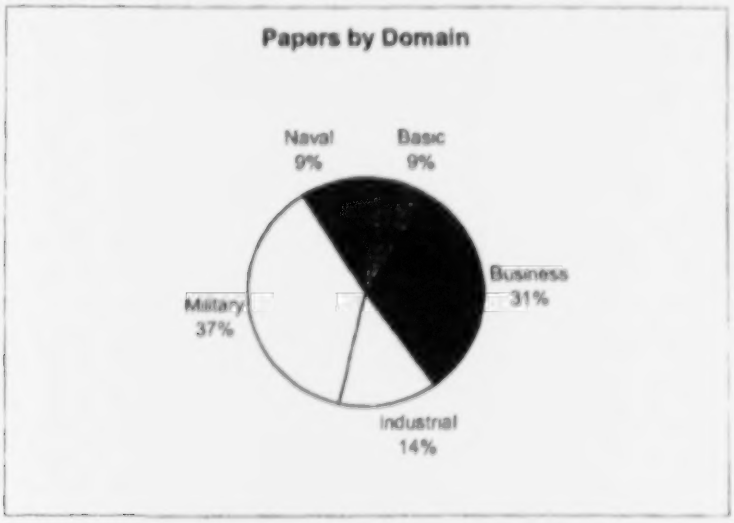

Figure 3. Papers by Domain.

The depth of the literature identified is illustrated in Figure 4. As indicated, much of the literature (49%) is in the category of Concept or Untested prototypes. This reflects the lack of maturity of the domain, in that more ideas have been generated than have been thoroughly tested. Even further, there is a notable lack of field evaluations of collaborative displays (1%), supporting this conclusion.

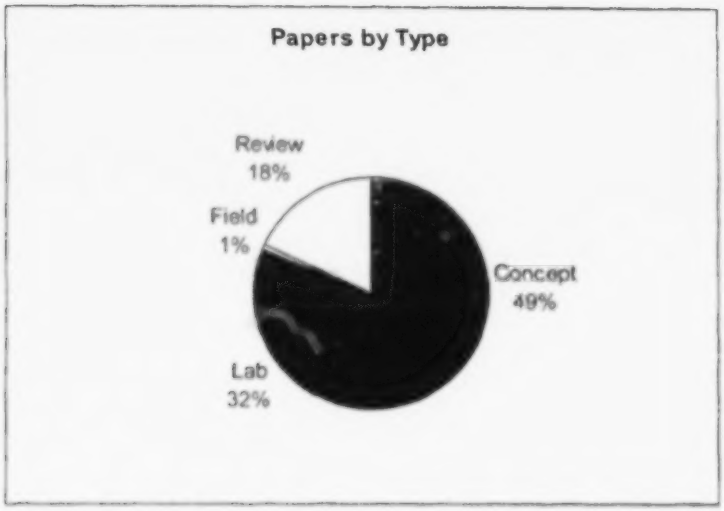

Figure 4. Papers by Type.

Another reason for the heavy weighting of literature in the area of untested concepts is that the area of collaborative displays is very much a technology-enabled field. By this we mean that as new technologies are developed, the possible forms of collaborative support change. The available technologies for collaborative support have been developing very rapidly. With such rapid technological expansion, there are many rewards in publication and commercialization for developing an exciting new concept. This pattern is seen to a large extent in the human-computer interaction literature and the business application category. However, the pattern continues in the Military and Naval categories, with a heavy concentration on new concepts and a slower movement towards evaluation in the laboratory or the field.

Many of the papers identified could have been classified as technology-oriented, meaning that they discussed a technology for supporting collaboration or a new collaborative concept. While these papers don't give immediate insight into human interaction with collaborative displays, we felt that it was unwise to discard them. Given the rapid development in the area, and the reality that human collaborative support is dependent on what technology can provide, staying aware of the possibilities provided by emerging technologies is important. Similarly the dependence of collaborative display support on technology indicates a risk or limiting factor when conducting research in this area, as technologies grow outdated rapidly. What is a limitation in one collaborative environment, may well be eliminated by the next release of technologies and collaborative display concepts.

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3.4.1 Comments on the Breadth and Depth of the Literature Identified

The literature search identified several very good papers that reflect rigorous studies of human interaction with collaborative displays or field trials. In general, however, the literature reflects a domain that has undergone rapid expansion and growth where the growth has outpaced researchers' ability to understand the impact of that growth. As evidence of this:

1. As indicated in Section 3.4 there are many concept type papers, reflecting concepts that are not yet thoroughly tested. While very prevalent in the Business area, this pattern appears as well in the Military and Naval literature. There are notably fewer papers reflecting laboratory studies or field evaluations. In particular, the literature base on field evaluations is quite weak (1%). In a mission-critical environment such as naval operations, there is a strong need for concepts to be thoroughly evaluated. This is clearly an area of collaborative display research that would benefit from more work. A challenge in this area, however, is that in most cases, the concepts developed are mature and complex. It would be difficult to evaluate these concepts and distill design guidance for human support without breaking the design concepts down. Furthermore, evaluating these concepts would require some reasonable control condition for experimentation.

2. There are many technology based papers. These papers review a new hardware or software development that may be useful for providing support for collaboration. In most cases, however, there is no human performance testing of these technologies, only technical testing.

3. There are many papers that examine team psychology, team mental models and shared situation awareness. These are all basic research areas that are critical to developing and evaluating collaborative displays. These papers can contribute to the measurement of team attributes and performance. The most interesting papers examine the influence of technology on team performance, however, there are fewer papers in this category.

4. There are sub-categories of literature that are evolving as the field grows and technologies change. These sub-categories may evolve into full areas of research in the future. Grouping by agents, collaboration can be discussed as human-human, or human-machine where machine can include robots, automation, intelligent agents, or other intelligent decision support systems. Grouping by collaboration in time, collaborative work can be synchronous (at the same time), or asynchronous (performed at different times). Grouping by location in space, collaborative groups can be in the same location, distributed but fixed, or distributed and mobile. Grouping by technologies there are large "group-view" type displays, basic PC/CRT stations, mobile or wearable devices. By modality there are visual displays, auditory displays, and occasionally haptic displays. As the literature in collaborative work grows, it will become increasingly

more important for researchers to identify which of these sub-fields they are examining.

5. By its very nature, designing a collaborative display requires an understanding of what makes a good "single-person" display and several of the papers retrieved examine those issues. Given the rapid development in the area, however, a notable gap in the literature is that there are no papers examining the trade-offs of "single-person" displays imported into a collaborative environment, or vice-versa, collaborative displays being used by single operators or reduced teams. This would seem to be a reasonable area to research as it is quite likely that people will first try to establish a collaborative environment by extending an existing successful single-operator environment. As well, there may be personnel impacts driven by team size, such as determining what happens when a team designed with "x" members, is reduced to "x-n" members but must still work in the same collaborative environment. This area of investigation would appear to be relevant in military environments where the loss of contact with personnel (or even the loss of personnel), or reducing staffing over time should be considered

3.4.2 Critical Weak Areas in the Literature Identified

The literature identified to date has a number of weaknesses, in terms of the ability to derive requirements for the acquisition or development of collaborative displays. These weaknesses include:

- There is very little literature on the testing of display concepts in the field and relatively low levels of literature on laboratory tests.
- The literature on supporting technologies is often lacking in human performance testing. There is a gap in the understanding of how these technologies influence human performance.
- The literature on team performance is often lacking in testing the influences of technology on performance. The reverse of the previous point, the researchers on team performance have often neglected to study the impact of technology on team performance.
- It is unclear how applicable Business application research will be to the Naval command and control environment without examining the papers in further detail.
- There are no papers that examine the scaling of technology from single person displays to collaborative displays, or from collaborative displays to uses in reduced team situations.

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3.5 Phase II: Papers Reviewed in Detail

Of the literature identified in the search, and summarized in Section 3.4, a number of papers were selected for more detailed review in Phase II of the project. This list was developed based on a review of the abstracts of the literature listed in Annex A in consultation with the scientific authority and other researchers at DCIEM. Unfortunately, the costing for the project provided budget for a review of only 15 papers, which was subsequently stretched to 21 papers. The next section gives a short summary of the paper and a brief comment on its applicability to understanding collaborative displays in naval C2.

- *Bolstad and Endsley, 1998. Information dissonance, shared mental models and shared displays: an empirical evaluation of information dominance techniques.* With a similar experimental setup to the 1999 work (see below), Bolstad and Endsley look at the effect of shared or not shared mental models. In this case, displays are shared or unshared and participants use both kinds of displays. Participants are university students in two person teams. The shared mental model is created by having participants read each other's job description. There is some evidence that working with shared displays before working with unshared displays was an effective combination. This paper is a good example of the use of shared mental models in understanding team performance and also shared vs. individual displays. The context is air contact identification, though the participants are university students.
- *Bolstad and Endsley, 1999. The effects of task load and shared displays on team situation awareness.* This study investigates the effect of two display conditions, an abstracted display with critical information only, and complete replicate "shared" display on two person team performance in an air contact identification and resource assignment task. Time to identify a target, process a target and correctness of the outcome were measured. No notable performance differences were found for the two display types. Like the previous work, this paper looks at two different display implementations for two person teams in an air contact situation.
- *Bolstad and Endsley, 1999. Shared mental models and shared displays: an empirical evaluation of team performance.* This paper is a shorter summary of Bolstad and Endsley, 1998.
- *Dekker and Fairburn, 1998. Collaborative failure in distributed crew systems.* From a distributed cognition perspective, Dekker and Fairburn analyse how collaboration has contributed to failure in actual accident situations, in particular the crash of an airliner in North Carolina. They discuss how miscoordination can lead to system breakdowns and how redundancy can lead to system failure. This paper was the only example of a distributed cognition perspective that we extracted. Although the context is not military, the paper provides a good description of what the author's term "collaborative failure", a collaborative extension of individual human error.
- *Gwynne et al , 1996. Evaluating for collaborative technologies for command and control teams.* Only parts of this report were available. Gwynne et al. examined

the effect of collaborative technologies such as email and group whiteboards on completeness and quality of SITREPS. No advantages were found for collaborative technologies. Group whiteboards and email, while certainly useful in planning stages, do not capture the element of simultaneous real time decision making.

- *Hoeksema, 1998. Effects of computer support on communication; decision making: a review of the literature.* This full report is in Dutch so only an English abstract was reviewed. Hoeksema reports on a literature survey for group decision support systems (GDSS) to support command and control in the Dutch army. Hoeksema argues that decision making by email is slow and should only be used for decisions without time pressure. Shared group displays should be used for information with strong spatial or visual components. While GDSSs do not guarantee better decisions, they can lead to more information being generated in brainstorming activities.
- *Hollingshead et al., 1993. Group task performance and communication technology: a longitudinal study of computer mediated versus face to face work groups.* Hollingshead et al demonstrate the use of McGrath's contingency theory for selecting technology for mediating group tasks. No differences were found between conditions in decision making performance. Experience with the various technologies was found to be the strongest predictor of performance. The contingency model was not supported. This paper is an example of an extraction from the area of CSCW and not a military domain paper.
- *Kline and McGrath, 1999. A review of the groupware literature: theories, methodologies, and a research agenda.* Kline and McGrath confirm in their review of groupware that although increases in information gathered have been reported, improvements in decision quality have not been shown. They proceed to summarize three major approaches to studying computer supported co-operative work: adaptive structuration theory which claims that groups adapt the technology to suit the group, self-organizing systems theory, which is largely descriptive and argues that groups are dynamic and adaptive, and contingency theory that argues that technology must fit the task. Kline and McGrath argue that these approaches are missing key contextual variables and the research is limited by being laboratory based and not exploring issues in the field. This paper provides a good summary of the dominant theories in the area of CSCW.
- *Lenox et al., 1999. Improving performance: should we support individuals or teams?* Using a low fidelity naval simulation, Lenox et al. investigate 3 person teams performing a target classification task. The study investigates the effects of three types of collaborative support agents. Results show little performance improvement with the collaborative agents.
- *McNeese et al., 1999. What is command and control coming to? Examining socio-cognitive mediators that expand the common ground of teamwork.* McNeese et al. propose a research program looking at the effect of team member schema similarity and fuzzy cognitive maps on performance in a C3 task. There are no experimental results reported in this paper. It does however, indicate two potential theoretical views for understanding team decision making.

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- *Miller et. al., 2000. Team decision making strategies: implications for designing the interface in complex tasks.* Miller et al. make two hypotheses: that time pressure will affect team performance, and that interface design can extend high performance under time pressure. Participants, ROTC cadets, play the roles of radar operator, and course of action generator in an aircraft identification task, using the same display in different rooms with only messaging capability between the rooms. Number of decisions, decision accuracy and number of messages sent are measured. Perceptual memory support was found to be effective, while feedback about other team member's decision priorities did not improve decision accuracy.

- *Nickelby & Co , 1997. Report on a short study into shared large screen display.* This study aimed to identify Human Factors issues associated with the use of large screen displays within warships in order to develop guidelines for the integration of large screen displays (LSD) for existing warships and in new warship procurements. As part of this study, Nickleby & Co. conducted a literature review on team factors in command team tasks, identified command team tasks in RN ships and submarines which may benefit from large screen displays, outlined implications associated with the installation of LSDs in ships/ submarines, and review LSD technology issues. The study results indicate that human factors guidance is lacking in terms of LSD implementation and team interaction with the displays, as well as required LSD functionality for team use and interaction.

- *Nickleby & Co., 1997. Shared large screen displays for warships.* This paper is a military summary of the Nickleby & Co. 1997 study on shared large screen displays.

- *Nunamaker et al., 1989. Experiences at IBM with group support systems: a field study.* Nunamaker et al. report on an in-the-field implementation of a group view display, with individual work station support for brainstorming activities. They argue that the system was effective for generating lists of prioritized requirements and resulted in person-hour savings when used for requirements generation. While not a military context, this paper is one example of a field test of a group view display.

- *Rasker et al., 2000. Effects of two types of intra-team feedback on developing a shared mental model in command and control teams.* Using university students performing a fire fighting task, Rasker et al. compared performance of teams in the same room versus different rooms (with messaging capability). Groups in the same room performed better. The authors cautioned though that these results may not generalize to intact teams.

- *Schmidt, 1991. Co-operative work: A conceptual framework.* Schmidt argues that co-operative work should focus on those tasks that cannot be done individually. He differentiates between augmentative co-operation, where many people do similar tasks concurrently and skills are not specialized, and integrative co-operation, that relies on skill specialization. He identifies a third type of co-operative work, debative co-operation, that concentrates on catching the reasoning errors of individuals.

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- *Shattuck et al., 2000. Cognitive integration: a study of how decision makers construct understanding in evolving contexts.* Shattuck et al use a tactical simulation and 21 active duty Army officers to demonstrate differences between novice and experienced participants. This paper is interesting for the performance differences noted between novice and experienced participants.

- *Sonnenwald and Pierce, 2000. Information behavior in dynamic group work contexts: interwoven situational awareness, dense social network and contested collaboration in command and control.* Sonnenwald and Pierce look at collaboration in a C2 environment during simulated scenarios. They describe situation awareness within the group and note that at times team members work towards their own interests, to the detriment of group performance. The data are obtained from army documents, interviews, and critical incident reviews. The paper is interesting for its use of situation awareness ideas and recording potential problems with collaboration.

- *Stubler and O'Hara, 1996. Group view displays: Functional characteristics and review criteria.* This Nuclear Regulatory Commission (NRC) report provides concise guidance on implementing group view and individual displays in a control setting. Guidance is supported with brief explanations for the guidelines, including literature references.

- *Vrablik, 1997. A methodology for performing collaborative decision-making across operating systems at the army brigade level.* Vrablik's work is an interim report looking at synthetic command forces for DARPA. Despite the title of the report, this work concentrates on collaborative algorithmic command agents that solve problems using constraint satisfaction. There is fairly little that is relevant to collaborative human problem-solving. Also extracted, *Vrablik, 1998, A design for performing collaborative decision making between Oss and commanders at the army brigade level* is similar.

- *Wilson et al., 1987. Team performance of a dynamic resource allocation task: comparison of shared versus isolated work setting.* Wilson et al. simulate a C3 condition using a team resource allocation task. Teams of three acquire targets worth different point values using individual or shared displays, graphical or text presentation. No significant differences are found for the individual versus the shared condition. An interaction is observed with display format, with poorer performance in the shared condition with the text display. The targets are presented without context and participants are novices.

3.6 Comments on the Literature Reviewed in Detail

Despite a fairly significant investment in research over the past few years, the effect of collaborative displays on team performance is not clearly understood (Kline and McGrath, 1999 states this clearly). Throughout the literature there is a surprising lack of definitive results showing that collaborative display technologies will improve team performance (Gwynne et al., 1996; Bolstad and Endsley, 1998; Bolstad and Endsley, 1999; Wilson and McNeese; 1987; Hoeksema, 1998). Despite the lack of strong performance results, there seems to be sustained interest in the study of

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collaborative displays due to an inherent belief that there are times when group decision making can outperform individual decision making. Technologically, the ability to engineer more elaborate collaborative environments is improving steadily. Collaborative tools are likely to be acquired and implemented regardless of whether or not their use has been validated empirically. As well, despite whether or not collaborative work improves team outcomes, the research shows that people rate collaborative work positively, another reason why the adoption of collaborative displays is likely inevitable.

The question, therefore, from a human engineering perspective, is not whether or not collaborative displays should or should not be adopted, but rather how to use this technology most effectively. There are indications of how collaborative displays can be used effectively and, possibly just as important, used ineffectively. The next sections discuss three relevant areas of collaborative display research – the implementations of group view displays, group decision support systems, and collaborative failure.

3.6.1 Group View Displays

For basic guidance on implementing collaborative displays as group view displays, Stubler and O'Hara's (1996) report provides sound and reasonable guidance that is still relevant five years later. From what we extracted, this is the most coherent set of guidelines for implementing large overview displays in a typical control room environment where operators will have access to individual displays at their own workstations. There is somewhat of a consensus in the literature that large overview displays are useful in highly spatial and highly visual environments because they provide a common frame of reference for the team (Stubler and O'Hara, 1996; Dekker and Fairburn, 1998; Hoeksema, 1998). Group overview displays, therefore, could have potential use in a naval environment, and the 1996 guide could be a useful standard to call up in procurement documents for future naval systems.

3.6.2 Group Decision Support Systems

In contrast, several of the papers that we extracted looked at the use of Group Decision Support Systems (GDSS). GDSS typically involve collaborative displays as well as software directed at facilitating group decisions. The literature suggests that while GDSS do not necessarily guarantee that better decisions will be made, when used effectively (Nunamaker et al., 1989 is an example of this), they can ensure that more information is considered and prioritized more quickly. In this way, GDSS could be useful in mission planning exercises. GDSS can also be used to reduce the hierarchical structure of teams, so that lower ranking team members feel comfortable proposing ideas. It would have to be determined whether or not this would be desirable in a naval environment.

3.6.3 Collaborative Failure

There are also indications in the literature of when collaborative displays could detract from team performance. Sonnenwald and Pierce (2000) observed that sometimes team members sabotage the collaborative effort in order to further their own individual interests. When problems are better handled by a single operator, having several people collaborating on the problem could slow down the speed of problem solving (Stubler and O'Hara, 1996; Dekker and Fairburn, 1998). Dekker and Fairburn (1998) provide a compelling description of how collaborative work can magnify individual decision making biases and lead to what they have called "collaborative failure". They also point to the effect of dynamics on collaboration – a team facing a highly dynamic event may be at a disadvantage if the dynamics of the collaboration do not match effectively with the dynamics of the event. They argue that good individual operator interface design is also critical to good collaboration. This study of how collaboration can go wrong is potentially very powerful, and could complement the study of individual human error. Given the criticality of avoiding failure in a naval environment, it would be desirable to see more papers examining these issues.

3.7 Theoretical Perspectives on Collaboration

As stated earlier, there is very little evidence in the literature from our small sample, that collaborative displays will necessarily result in better team outcomes as measured by decision quality or time to decision. There are, however, theoretical and methodological reasons in the research base that suggest why these results are not appearing. So while one cannot say that collaborative displays will aid performance, one cannot say that they will not aid performance either. The research does not support either conclusion at this stage.

There are a multitude of perspectives on collaborative work ranging from theories on teamwork and group performance to more recent theories from the researchers in computer-supported collaborative work that describe the interaction of technology on teamwork and performance. Some perspectives are extensions of theories of individual decision making to the group situation, notably Endsley's extension of her theory of situation awareness (Endsley, 1995) to "shared" situation awareness (cf. Bolstad and Endsley, 1998; 1999 also used by Sonnenwald and Pierce, 2000), and the extension of the mental model research to "shared or team" mental models (Bolstad and Endsley, 1998; Rasker et al., 2000 also use this idea and can be referred to as examples of shared mental model research). The other popular research perspective comes from the area of Computer Supported Co-operative Work (CSCW). These two approaches are discussed in the following sections.

3.7.1 Collaborative Failure

Theories of individual decision making all have their weaknesses and when these theories are extended to the group or team situation, these weaknesses can be magnified. Bolstad and Endsley (1998, 1999), as an example, have

tried to extend the theory of individual situation awareness to the group or "shared" situation awareness. There is very little difference theoretically between shared situation awareness and individual situation awareness beyond the concept that in the team condition, the elements of situation awareness are now spread over different people. There is not an analytic discussion of what is now different in the team situation. In many ways, there is not a good description of what elements comprise situation awareness for an individual and hence, what would comprise shared situation awareness for a team in a group environment. Sonnenwald and Pierce (2000) provide a brief description of what elements might comprise situation awareness in their paper, but beyond arguing that shared situation awareness is desirable, there are no concrete measures of the concept. Similarly, Bolstad and Endsley (1998) use shared situation awareness as a dependent variable (in the sense that it is hypothesized that shared displays will increase shared situation awareness); however, the actual measures in the study reported in Bolstad and Endsley (1999) are typical performance measures of time to process a target and correctness of target classification. There does not appear to be a way of measuring shared situation awareness itself. This difficulty in analysing the elements of shared situation awareness, and then in concretely measuring shared situation awareness are artifacts that have transferred to the team environment from weaknesses in the perspective as originally applied to individual decision making. Characterizing the entire situation awareness area on such a brief review is admittedly unfair, however, given Endsley's strength in the situation awareness area, we would expect to see this weakness repeated in at least some of the shared situation awareness literature.

The shared mental model perspective is subject to the same risks, taking the concept of an individual mental model and arguing that the members of effective teams will hold similar mental models. In general the individual mental model research struggles with the definition of what is a mental model and how can a mental model be measured (Moray, 1996). Looking at Bolstad and Endsley (1998) and Rasker et al. (2000), we see these theoretical problems translated into the team environment. For example, in creating a shared mental model condition, the researchers have the team members read the job descriptions of the other team members (Bolstad and Endsley, 1998). In Rasker et al. (2000), the researchers create the shared mental model condition by allowing intra-team feedback. These two relatively vague approaches do not suggest that the researchers have strong grasp of what elements are critical to creating a shared mental model when a shared mental model is effectively an independent variable in an experiment. In both of these studies which aspire to create shared mental models, there is no further testing in the research to confirm that this approach did result in a shared mental model. We would argue that this could be due to a lack of consensus in how mental models in general can be measured. This reflects a problem of experimental control in these two studies (Bolstad and Endsley, 1998; Rasker et al., 2000). There may be stronger literature in the area of shared mental models, but again these are recent papers from noted researchers in the area.

A further assessment of the shared mental model literature should look at whether the concept of shared mental models can propose what elements are most critical in a shared mental model, how a shared mental model can reliably be measured, and how well these measures correlate with performance.

3.7.2 Computer Supported Collaborative Work (CSCW) Perspectives

Kline and McGrath (1999) provide a useful review of the key theories from CSCW. They summarize the basics of Adaptive Structuration Theory, Self-Organizing Systems Theory, and Contingency Theory. They argue that these perspectives stress the nature of the social system that the technology is introduced to and often answer questions on whether computer technology can support the collaborative environment with "it depends". They propose that this lack of predictable results is due to missing key contextual variables that could reduce the variability of the predictions. This is a hypothesis and is not tested. They also note our observation that the CSCW literature has not generally made an impact on the quality of decision making or in "bottom line" outcome variables.

As examples of the CSCW perspective, we extracted a paper by Hollingshead et al. (1993) which is representative of the contingency theory approach to CSCW and Dekker and Fairburn (1998) which presents a distributed cognition perspective, a theoretical descendent of self-organizing systems theory. Contingency theory reasonably proposes that different technologies fit different task types. Hollingshead et al.'s results, however, did not support this conclusion, but rather found that experience with the technology was the greatest predictor of how well the technology supported the teams, which may support Kline and McGrath's (1999) contention that some of the CSCW perspectives are ignoring key contextual variables.

Dekker and Fairburn (1998) is not an empirical study but rather a description of "collaborative failure" in distributed and complex systems. They examine the crash of flight 1016 at Charlotte, North Carolina from the distributed cognition perspective. Dekker and Fairburn argue that many of the aspects of successful collaboration conspired in this particular incident to cause "collaborative failure". Being in effect a case study, there is not much guidance on how to improve collaborative work in the future. Dekker and Fairburn do, however, present a powerful analysis that is credible given the richness of the environment that they have examined. It would be worthwhile to extract more work from this area.

3.7.3 Coverage of Theoretical Questions

To a large extent, most of the available literature focuses on the effect of collaborative displays or collaborative decision environments on decision making. Decision making is an end result of many different information processing activities such as focus of attention, information gathering,

perception and memory. To a large extent, these intervening processes seem to be ignored by the literature and there is room for new contributions to be made here. Work that looked at other information processing stages could be the start of a more diagnostic research program in collaborative displays that could begin to explain why one display performed better than another display.

3.8 Methodological Issues (Research Quality)

The research results in the area of collaborative displays are generally weak. This effect may be a result of weaknesses in how the work has been conducted and in the theoretical bases on which the work has been founded. Some of the methodological issues prevent the work from making strong contributions to the understanding of supporting collaborative work, which is the intention of the research itself. Many of these issues can be corrected with better designed experiments and a more targeted approach to understanding collaborative support. The primary concerns with research quality are discussed in the following sub-sections, including:

- Unrepresentative Subject Groups
- Unrepresentative Tasks
- Inappropriate Measures
- Poor Interface Design

3.8.1 Unrepresentative Subject Groups

A typical methodological issue we have noted is the use of unrepresentative subject groups such as undergraduate students. Wilson et al., 1987, Bolstad and Endsley, 1998; 1999; Rasker et al., 2000; Lenox et al., 1999 are examples of using undergraduate students in military simulations where presumably the authors would want to generalize to military personnel. Gwynne et al. (1996), Sonnenwald and Pierce (2000), Shattuck et al., (2000) had access to actual military personnel. McNeese et al. (1999) reported results with college students but state intentions to move their work into studies of military personnel. Nunamaker et al., (1989), while not reporting a military environment do report on the use of group support systems in the context of a field study with IBM personnel. Given the differences between novice and expert performance (from our papers, Shattuck et al., 2000 provides an example of this), the subject group used by the researchers should be considered when assessing these papers. In many cases, the title of the paper or the abstract does not provide enough information to determine the subject group used in the work. The second way in which the subject group can affect the results of team research is in terms of team cohesiveness. In a naval environment, teams will have worked together or in similar roles for several months in most cases. Considering also that Operations Room Officers (OROs) and Commanding Officers (COs) have progressed through the ranks, this should give them a very strong mental model of the work of some members of the Operations Room team. Recruiting random undergraduate students does not capture this type of team dynamic. One

study that we extracted, Lenox et al., (1999) made the effort to recruit "intact" teams, a method which should add some realism to their study. None of the other studies we extracted took this approach.

3.8.2 Unrepresentative Tasks

The design of experimental tasks can also affect the results of experiments and the generalizability of the work to a naval context. Many of the tasks presented in the literature that we extracted are relatively simple, and perhaps do not even require collaboration to perform them successfully. This could be one reason that strong experimental results for improved performance with technologically supported collaborative work are not apparent. Improvements due to display support will be more apparent with more complex tasks. If the tasks themselves are not complex enough to require collaboration, then it is unlikely that support for collaboration will aid the performance of the task. Papers we extracted where this effect could be occurring might include Bolstad and Endsley (1998; 1999), Lenox et al. (1999), and Wilson et al., (1987). In contrast, Rasker et al.'s (2000) firefighting task provides an example of a still relatively simple task that has been divided in such a way as to require collaboration. An "observer" performs fire detection, an "allocator" performs the dispatching of firefighting teams and equipment. Bolstad and Endsley (1998, 1999) also used a task with defined roles. In comparison with a naval environment, however, both of these tasks (Rasker et al., 2000; Bolstad and Endsley, 1998) are quite simple.

3.8.3 Inappropriate Measures

A well conducted study will show a balance of process and product measures. Given the criticality of military events, product or outcome measures are likely of the greatest interest. Several of the papers we extracted report on decision quality or accuracy, time to make a decision, or number of decisions made (Miller et al., 2000; Bolstad and Endsley, 1998 are good examples of this). Many of the studies also report process measures, such as number of messages sent, number of repeated behaviours, or subjective workload measures. Shattuck et al., (2000) is an example of a study that recorded process measures only, which limits the value and the message of the work.

3.8.4 Poor Interface Design

To a certain extent, the emphasis on collaborative aspects may cause researchers to ignore the design of the interfaces used in their studies. Although the actual graphical form of the interfaces being used is not the topic of the study, these interfaces could be influencing the results that are being obtained. Several of the studies are using what appear to be fairly rudimentary interfaces with very little justification for why they have chosen that particular interface design. For examples of this, we would point to Bolstad and Endsley (1999) and Wilson et. al. (1987).

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3.9 Future R&D Directions

From the review of the literature, there are several different directions that could be pursued. These directions are drawn from the general comments and issues discussed in the previous section. From this review, we have identified six potential research directions. The first direction, and likely a precursor to the other directions, proposes a more targeted review of the literature. The next two directions seek to correct weaknesses we observed in the literature through unrepresentative experimental design and undiagnostic experimental measures. The fourth direction proposes developing a stronger theoretical understanding of human cognition in group environments by scientifically dissecting the concepts of distributed cognition or shared situation awareness. The last two directions call for greater recognition of the individual in collaborative support, first by extending known successful individual display design ideas, and second by developing a stronger understanding of how to allocate individuals and teams to problems and how technological augmentation can influence that allocation.

3.9.1 Further Review of the Literature

The reviewed literature is an admittedly small sample of the collaborative display research (i.e. we reviewed 21 of 389 identified papers). Given the breadth of the area, it would be worthwhile to review literature in very specific directions. Expanding the literature review without narrowing the direction of it would not be very valuable. The research ideas discussed in the following sections may indicate worthwhile directions for further detailed literature review.

3.9.2 Representative Research

There is a need for representative research in the area of collaborative displays. Tasks that are not adequately complex may not require collaboration in order to complete the task. Efforts to compensate for this by splitting the task over two people, and in effect restricting their information (seen in Bolstad and Endsley, 1998; Lenox et al., 1999) are not likely to generate results which can be reliably transferred to a complex naval environment.

Representative participants are also needed. Experience effects are regularly measured (e.g. Shattuck et al., 2000), therefore, research with undergraduate participants should only be considered a trial run for eventual research with experienced personnel. In collaborative situations, experience as a team needs to be considered as well as individual experience. For this reason, recruiting intact teams is a reasonable approach to follow.

In order to provide relevant task environments, various levels of modelling and simulation must be considered to establish proper experimental environments. Task Network Modelling (TNM) could be considered to evaluate the impact of collaborative displays on team performance, if the TNM was based on an actual naval C2 team. Part task simulations from naval command environments, with accurate scenario generators would

provide the next level of accurate experimental platform, where intact teams could be inserted for evaluation purposes. Training simulations would provide the next level of evaluation platform, where prototypes of collaborative display concepts could be inserted for evaluation of their impact on team performance. The final level of simulation would be live simulation, whereby field trials are conducted of collaborative display concepts on actual ships. An R&D program that progressed analysis along these levels of experimental realism would appear warranted to study this complex area.

3.9.3 Development of Measures

In reviewing the literature, many researchers seem to be uncertain about what measures to use in a team situation. The number of decisions made, decision quality and team communications are common choices. However, these measures are not diagnostic for someone who is deeply interested in how to implement collaborative displays effectively. In order to understand how collaborative displays can effect distributed cognition, or shared situation awareness, a set of reliable measures of these concepts is required. Information processing measures from the performance of individuals may be able to be adapted. In general, it should be recognized that strong individual cognitive performance will improve team performance, therefore these measures still have validity in the team environment. As just one example, the memory recall paradigm employed by de Groot (cited in Wickens, 1992) to extract the understanding of meaningful groups or chunks of information could be used to measure the understanding of individual team members and could point to areas of strong or weak situation awareness. Having very specific measures of how different collaborative displays are affecting individual information processing should not only yield more definitive results, it will allow researchers to target areas for improvement in collaborative support.

Along with collecting performance measures, there are good reasons to collect measures of error or poor team performance. Although human error is often used within individual cognition, it does not seem to be adapted to the team situation. However, Dekker and Fairburn (1998) show the criticality of understanding team failure in complex situations. Sonnenwald and Pierce (2000) also demonstrate that strong individual performance can represent failure at the team level, if it leads to information hoarding or sabotage.

There is also a need for better measures of team performance as a whole. The measurement of team communication is an indirect measure and may not correlate with strong team performance under all situations. For example, does a very cohesive team with strong shared situation awareness communicate more because of their need to share information, or communicate less because they have such strong mental models of each other's tasks that they need to ask fewer questions? Perhaps communication level is a determined by other factors in the situation, such as the familiarity of the task or experience with the technology (as Kline and McGrath, 1999 suggest).

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3.9.4 A Deeper Understanding of Distributed Cognition or Shared Situation Awareness

At an intuitive level, the concepts of shared situation awareness or distributed cognition have promise for improving the support of teams in complex situations. At a practical level, these concepts require more refinement and study to be understood and used effectively. The first task is to analyse these concepts into smaller constituent parts and answer specifically questions such as "What does having good shared situation awareness mean?". The development of more diagnostic measures as discussed in the previous section is a key aspect of refining this understanding. In our view, the approach needs to become more scientific. For example, given a particular collaborative display manipulation (independent variable), what is the effect on a particular measure of situation awareness (dependent variable). The current approach of using loosely controlled display conditions and measuring global outcome measures (such as decision quality) does not generate useful empirical information, or validate the support of shared situation awareness. In contrast, more controlled display conditions, with intermediate measures of cognitive processing coupled with outcome measures would begin to connect display manipulations with shared situation awareness, and shared situation awareness with global results.

3.9.5 Extension of Individual Interface Design Research to Collaborative Displays

There needs to be a stronger connection between individual display design and collaborative display design. First, the displays used in collaborative display research need to demonstrate that they adhere to the basic principles of human-computer interaction that are used in individual display research. The graphical form of displays can have powerful effects on human performance. When researching collaborative display support, it should be confirmed that the research is founded on well designed displays before determining the particular collaborative manipulation. In the literature that we reviewed, there was no evidence that this step had been taken.

Furthermore, research on individual displays that have been successful in improving human performance should be considered for adaptation to collaborative environments. Practically, future collaborative displays will be extensions of today's individual displays. Therefore, the study of how best to apply individual display technologies should be very relevant. Examples worth pursuing could include the adaptation of Ecological Interface Design (Vicente and Rasmussen, 1992), configural displays, as well as within display concepts such as the proximity compatibility principle (Wickens and Carswell, 1995).

In addition, the application of the collaborative displays guidelines developed by Stubler and O'Hara (1996) to naval displays should be considered for further evaluation.

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3.9.6 Comparison of Individual and Collaborative Decision Making

One of the key questions that needs to be answered by the collaborative display research area is how to best apply individual and collaborative displays. This question is a derivative of when to use group decision making versus individual decision making. At the moment the research areas are divided, with researchers either investigating individual displays or collaborative displays. There are few examples (we did not extract any) comparing individual to team performance under the same conditions. In terms of implementing collaborative displays, however, this is one of the most critical questions to answer. Installing collaborative displays where only individual displays are needed, could actually absorb more personnel resources than required if more people than needed are involved in making decisions that could have been made effectively by one person. Given the recent interest in reducing personnel numbers on naval ships (demonstrated in the United States by the DD-21 project, and recent DRDC studies on crewing reduction technologies in support of future Canadian ship classes), the correct allocation of personnel to problems is very important. Research is needed comparing individual and group performance in naval decision making that examines alternative ways of allocating personnel to naval problems based on hypotheses about individual and group cognition. In support of this research, the influence of technology to augment both individual performance and team performance and allow the reallocation of resources is required. A collaborative display should not be implemented until it can be confirmed that a collaborative display is more effective than an individual display in that given situation.

3.9.7 A Collaborative Display R&D Program

When the above future R&D areas are combined, a three pronged R&D program evolves with the following suggested elements:

1. Extension of Literature Review and Theoretical Development. The literature review should be extended to further define the collaborative aspects of naval command and control (which may also require task analysis), to propose measures of team performance and shared cognition in the naval environment, to further investigate the theoretical differences between individual and collaborative decision making, and to further identify any known impacts of collaborative technology on team performance. This review should result in the development of a theoretical framework for the investigation of the impact of collaborative displays on complex team problem solving in naval, and other, environments. This output can then not only guide further R&D in this area, but also indicate links with related R&D programs within DRDC/DND, such as work on leadership and team performance or work on the training effect of replacing live team members with virtual agents in distributed training environments.

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2. Experimentation with Naval Collaborative Displays. An experimental environment must be created for naval command and control, perhaps making use of existing simulations in this area. This environment must allow intact teams to be inserted into realistic naval operational scenarios, and must provide a underlying data structure that will support the evaluation of both individual decision making at individual displays and the creation and subsequent evaluation of collaborative displays within this same environment. Such a facility would obviously require in-house or contract systems engineering support to assist with configuration of the required individual and collaborative display environment. Once this experimental platform was established, then the recommended future R&D in the areas of (i) extending individual interface design to collaborative displays, (ii) comparing individual and collaborative decision making, and (iii) developing a deeper understanding of distributed cognition or shared situation can be investigated. Such a facility could be established in DCIEM, or at either an industrial site or local university to take advantage of shared funding sources.

3. Coordination of Collaborative Display Research. A program of research in the human factors aspects of collaborative displays, with a goal of generating requirements and design guidance for future military acquisitions, requires a coordination function. Not only is there the opportunity to centrally compile and distribute the results of research in the areas described above, but also to coordinate the application of collaborative measures applied on other experimental programs. For example, large simulators will regularly have intact teams conducting command and control scenarios with automated and manual data collection activities (often for training purposes at this time), or DRDC technology demonstrators (such as the Future Armoured Vehicle System with four linked armoured vehicles) will be evaluating the impact of prototype displays on both individual and group performance. Any future program studying collaborative displays should identify itself across DRDC and DND, promote the sharing of information on measurement of team performance and collaboration, provide scientific support to other teams to include proper team measures in their studies, and act as a clearing house to regularly integrate the results of research from all studies in the area with evolving theories or frameworks. In this way a comprehensive set of guidance can be developed for all environments in DND, based on contextually relevant operational studies. The development of a web site on this topic within the DND network would be beneficial in facilitating this integration function by the DCIEM team. The Human Systems Integration project web site, managed by DSTHP 3, could be used for this purpose pointing to a Scientific Authority at DCIEM as the topic coordinator.

4. Conclusions and Recommendations

A review of the literature related to collaborative displays has been completed, in order to provide commentary on the breadth, depth and quality of the literature and to recommend areas of future research.

In terms of breadth, the types of papers identified indicated that there were many relevant papers in the Naval and Military area. There is also a substantial base of literature from Business applications, most of which is directed at collaborative work, team management or conferencing.

This literature base, however, does not have much depth. Much of the literature (~50%) is at the concept of untested prototype phase of development. This reflects the lack of maturity of the domain, in that more ideas have been generated than have been thoroughly tested.

In cases where actual evaluations of collaborative display technologies have been conducted there are a number of concerns with the quality of the research, particularly as a result of unrepresentative subject groups, unrepresentative tasks, inappropriate measures, and poor interface design of the candidate display.

In order to extend the literature, in a manner that would generate valid guidance for future collaborative display acquisition teams in the naval environment it is recommended that a three pronged R&D program be conducted, as follows:

1. Extend the Literature Review and Collaborative Display Theoretical Framework.
2. Conduct Naval Collaborative Display Experiments
3. Coordinate and Consolidate Collaborative Display Research

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List of symbols/abbreviations/acronyms/initialisms

C2	Command and Control
C3	Command, Control and Communication
CANTASS	Canadian Towed Array Sonar System
CPF	Canadian Patrol Frigate
CSCW	Computer Supported Co-operative Work
CO	Commanding Officer
DARPA	Defence Advanced Research Projects Agency
DRDC	Defence Research and Development Canada
GDSS	Group Decision Support System
ICE	Integrated Command Environment
NRC	Nuclear Regulatory Commission
ORO	Operations Room Officer
PDA	Personal Digital Assistant
R&D	Research and Development
SITREP	Situation Report
TIAPS	Towed Integrated Active Passive Sonar

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13. DOCUMENT ANNOUNCEMENT

Unlimited announcement

(U) A literature review project has been completed to investigate the literature on collaborative displays as they relate to command and control in general and naval command and control specifically. Using a defined set of keywords and literature sources the project team identified a total of 461 papers, of which 392 of the most relevant papers have been rated using a literature relevance matrix. Of the literature identified in the search, 21 papers were reviewed in detail in Phase II. The literature review identified a series of weaknesses in the collaborative display literature related to practical evaluations of the technology, lack of human performance testing, lack of context in the research, and an absence of research to investigate the scaling of technology from single person to collaborative displays. To address weaknesses in the literature, and to develop guidance for future acquisition projects and operational teams, a three pronged R&D program is recommended to (i) extend the literature review and theoretical development of the domain, (ii) experiment with naval collaborative displays, and (iii) coordinate and integrate collaborative display research throughout DRDC/DND.

(U) Nous avons réalisé un projet de recension des écrits sur les affichages partagés pour évaluer leur utilité pour le commandement et le contrôle en général, et pour le commandement et le contrôle navals en particulier. À partir d'un ensemble défini de mots-clés, l'équipe de projet a recensé 461 articles dans un ensemble de banques documentaires. Elle a ensuite classé les 392 articles les plus appropriés (pertinents) avec un tableau de pertinence. Au cours de la phase II, elle fait l'étude détaillée de 21 de ces articles. Notre examen des écrits nous a permis de dégager certaines faiblesses des articles, notamment : l'évaluation pratique de cette technologie, le manque d'essais sur la performance humaine, le manque de contexte pour la recherche et l'absence de recherche sur comment modifier la technologie pour passer des affichages individuels aux affichages partagés. Pour éliminer ces faiblesses dans les écrits et élaborer les consignes à suivre à l'avenir lors de projets d'achat et par les équipes, on recommande de mettre en œuvre un programme de R. et D. comportant trois volets, soit (i) élargir l'étude de recension des écrits et le développement théorique du domaine, (ii) procéder à des essais avec les affichages partagés et (iii) coordonner et intégrer les recherches menées sur les affichages partagés au sein de RDDC/MDN.

15 KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) collaborative displays; shared displays; naval displays; operations room displays; large displays; Canadian Patrol Frigate displays